

The image is a promotional graphic for a webinar series. It features a background of a desert landscape at sunset, with a stylized map of the Arab region overlaid in the foreground. The top half of the image has an orange-to-yellow gradient, while the bottom half has a blue gradient. Text and logos are placed within these colored sections.

RICCAR
Regional Initiative for the Assessment of
Climate Change Impacts on Water Resources and
Socio-Economic Vulnerability in the Arab Region

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Regional Initiative for the Assessment of Climate Change Impacts on Water Resources & Socio-Economic Vulnerability in the Arab Region

**WEBINAR SERIES ON
CLIMATE CHANGE ANALYSIS USING GIS TOOLS**

Module 6:
RICCAR integrated vulnerability assessment methodology

UNITED NATIONS
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ESCWA



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Climate Change Impacts on Water Resources and
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Webinar Series

- **Module 1:** RICCAR regional climate modelling and hydrological modelling datasets: An introduction
- **Module 2:** Viewing NetCDF regional climate modeling datasets in GIS
- **Module 3:** Extracting tabular data from NetCDF climate files for use in other models and applications
- **Module 4:** Creating a regional climate model ensemble using GIS and extreme events indices
- **Module 5:** Accessing global and regional climate datasets and platforms
- ✓ **Module 6:** [RICCAR integrated vulnerability assessment methodology](#)

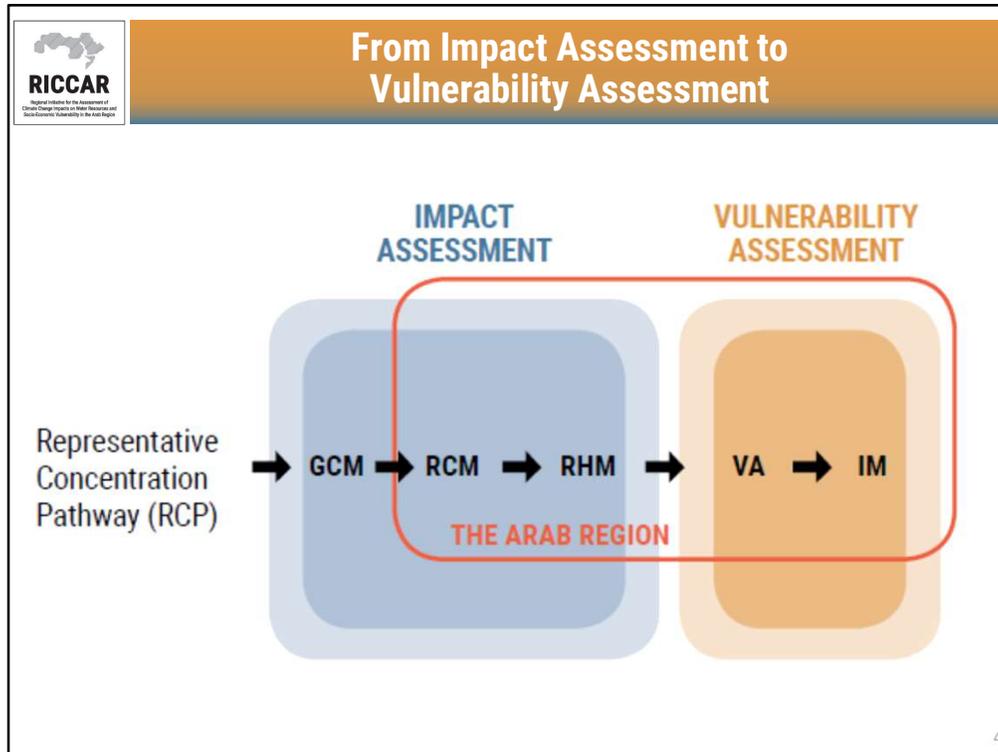
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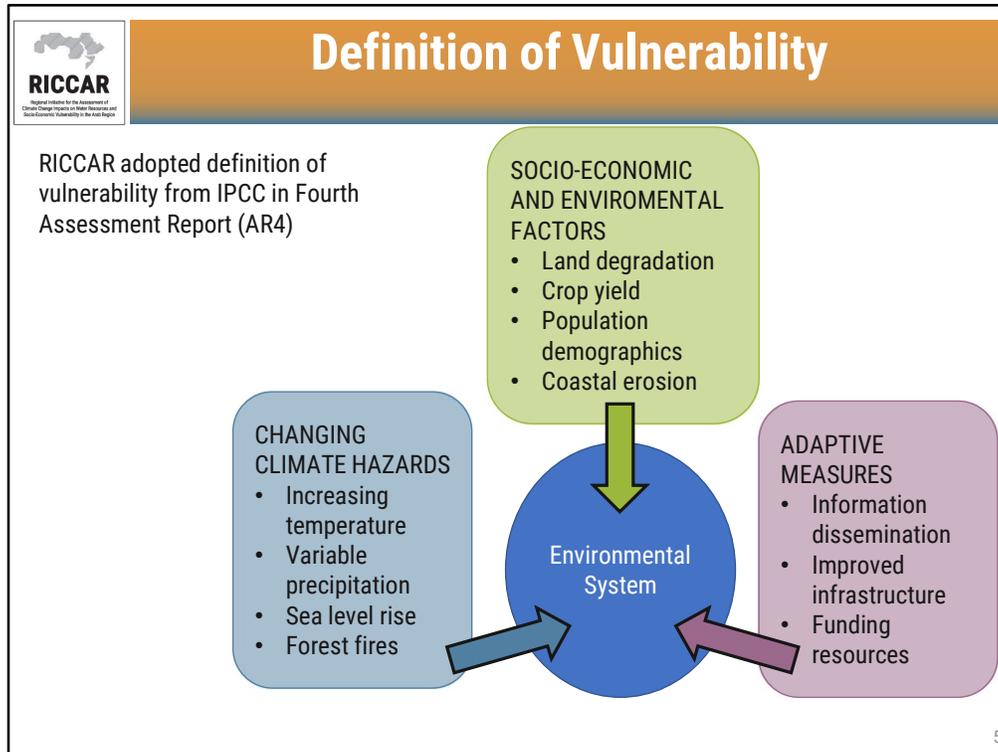
Module 6: Contents

- Why are geospatial vulnerability assessments useful at the regional, basin, local and sectoral scales?
- RICCAR integrated vulnerability assessment methodology
- Vulnerability assessment data aggregation
- Integrated mapping tools

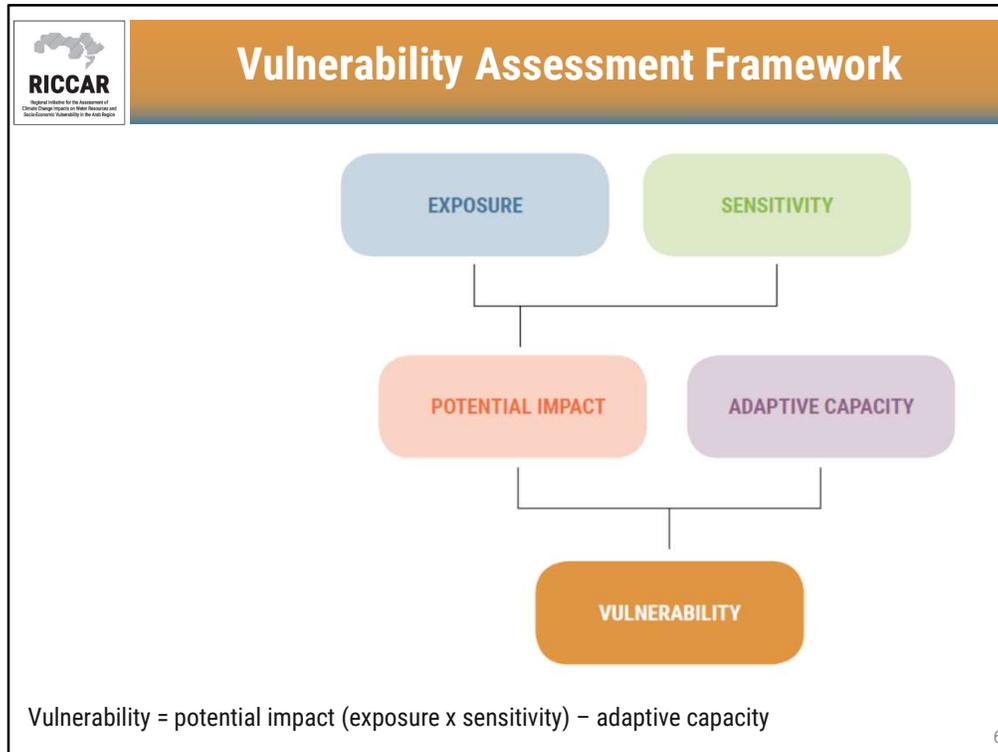
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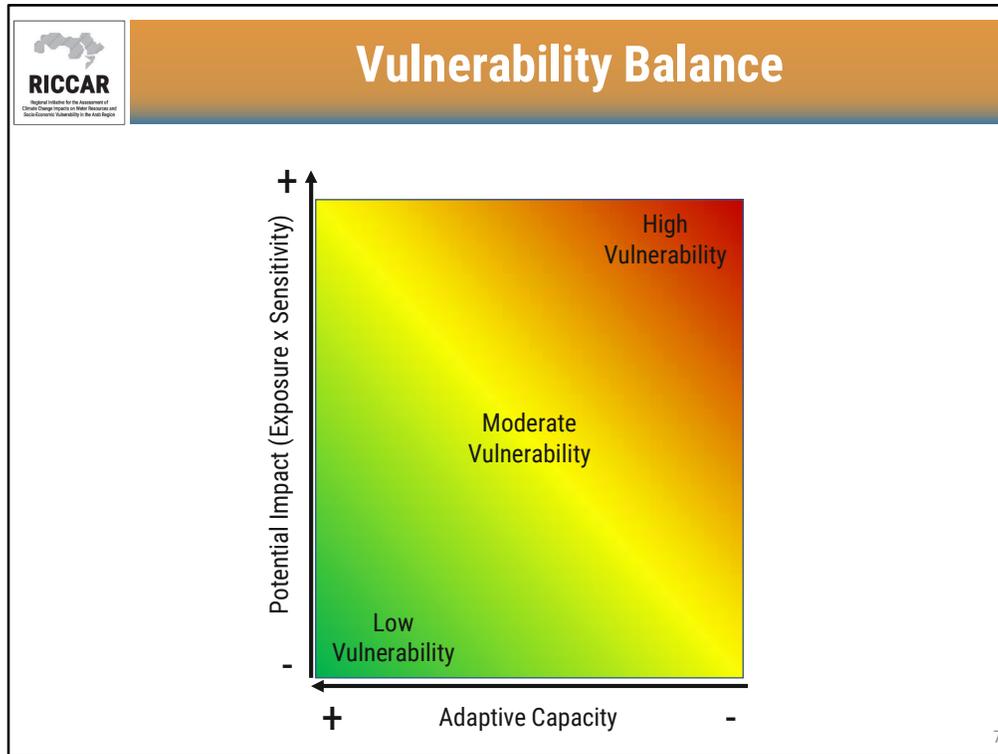
- Webinar modules thus far have focused on the Impact Assessment, which entails the downscaling of global climate models (GCM) using regional climate modelling (RCM). Furthermore, the RCM outputs were used to conduct regional hydrological modelling (RHM).
- The impact assessment outputs were used to conduct vulnerability assessments (VA) and results were displayed using integrated mapping (IM) tools.



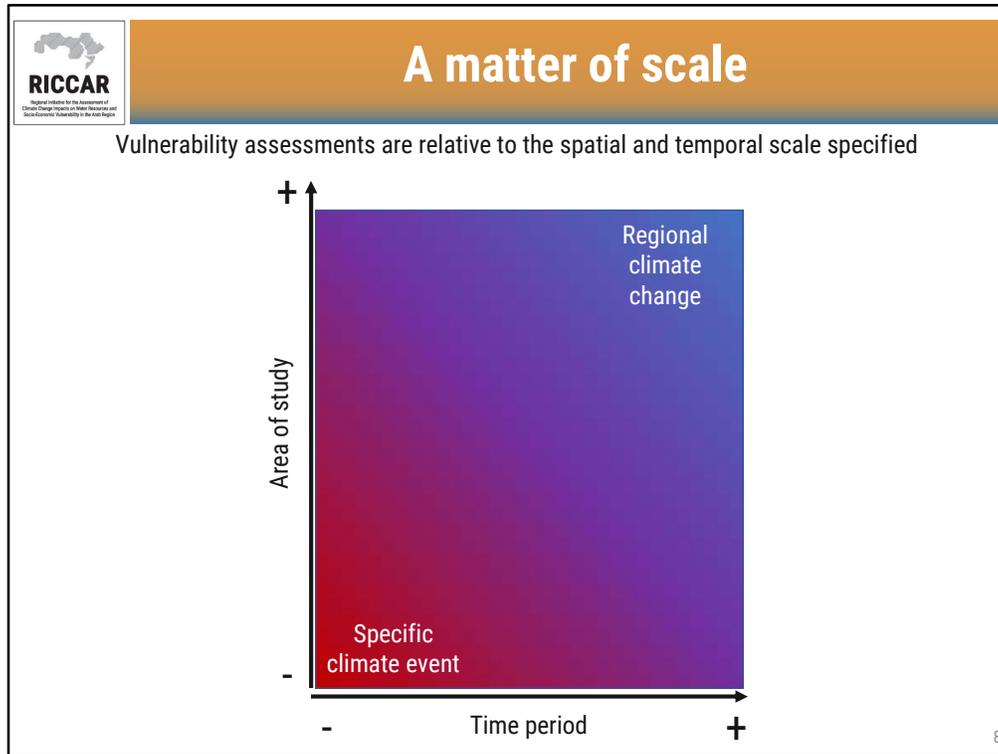
- In the context of climate change, the vulnerability of an environmental system is influenced by 3 primary components: changing climate hazards (i.e. increasing temperature, variable precipitation, sea level rise, forest fires), socio-economic and environmental factors (i.e. land degradation, crop yield, population demographics, coastal erosion), and adaptive measures (i.e. information dissemination, improved infrastructure, funding resources)
- Environmental systems studied for RICCAR include 9 subsectors: (a) water availability, (b) area covered by forests, (c) area covered by wetlands, (d) water available for crops, (e) water available for livestock, (f) inland flooding area, (g) water available for drinking, (h) health conditions due to heat stress, and (i) employment rate for the agricultural sector.



- **Exposure** refers to changes in climate parameters that might affect socio-ecological systems.
- **Sensitivity** provides information about the socio-economic and environmental make the affected systems particularly susceptible to climate change.
- **Potential impact** is the combination of exposure and sensitivity.
- **Adaptive capacity** considers the ability and willingness to adopt measures to reduce potential impact.



- Low vulnerability is the result of low potential impact and high adaptive capacity.
- High vulnerability is the result of high potential impact and low adaptive capacity.



- Vulnerability assessments can be conducted for small areas of study over short time periods, suitable for assessing extreme events (such as flash flood or heat waves) for a targeted area.
- For RICCAR, the vulnerability assessment was conducted for the entire Arab region to assess climate change impacts (using 20-year periods).
- Although vulnerability assessments can be effective tools, they are only relative to the area of study and time period for which the study is conducted.

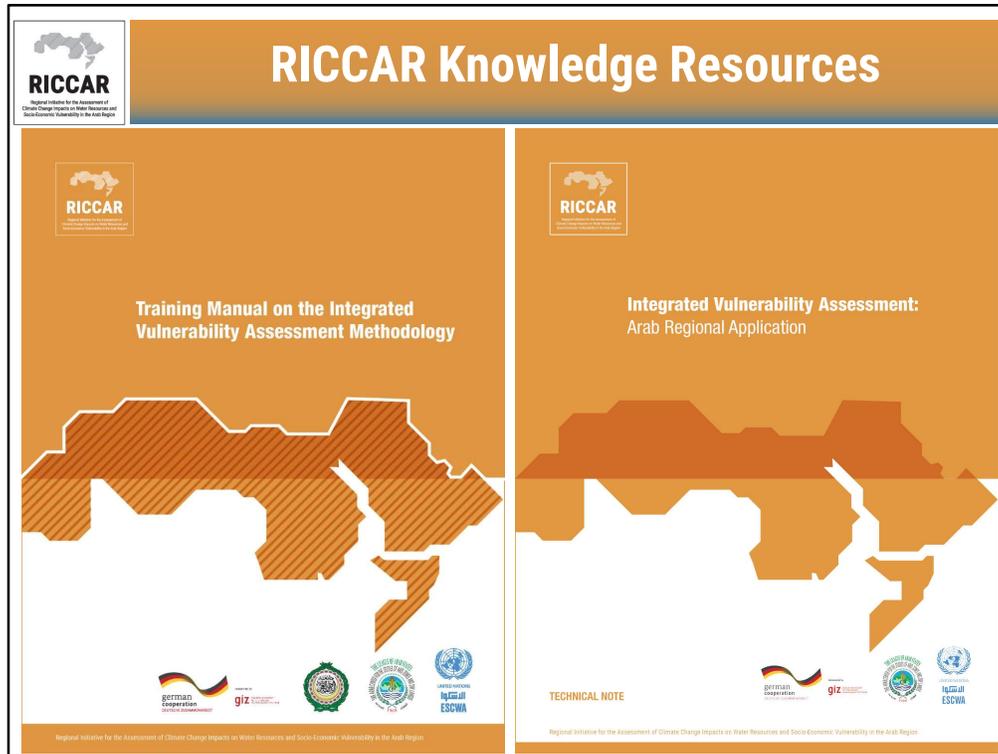


How to measure vulnerability

Vulnerability is measured using **exposure**, **sensitivity**, and **adaptive capacity** indicators

Geo-spatial indicators are needed to perform **integrated mapping** of the **vulnerability assessment**

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- Knowledge Resources are available from www.riccar.org. Both documents are currently only available in English.
- The training manual describes in general how to conduct vulnerability assessments and associated GIS tools.
- The technical note (on the right) describes how the VA methodology was applied at a regional scale for RICCAR.

The image shows the cover of a technical report. At the top left is the RICCAR logo with the text 'Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region'. The main title 'RICCAR Knowledge Resources' is in a large orange banner at the top. The report title 'Integrated Vulnerability Assessment Application on the Lebanese Agricultural Sector' is centered on a green background. Below the title is a stylized map of the Arab region with a white arrow pointing to Lebanon. At the bottom left, it says 'TECHNICAL REPORT' and lists logos for the Republic of Lebanon, Ministry of Agriculture, CNRS, and UNESCWA. The number '11' is in the bottom right corner.

- Available in English only from www.riccar.org



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Indicator sources

- RICCAR Regional Knowledge Hub Data portal
- World Bank Mashreq Water Resources Portal - <http://spatialagent.org/Mashreq/>
- FAO GeoNetwork - <http://www.fao.org/geonetwork/srv/en/main.home>
- FAO Hand-in-Hand Geospatial Platform <https://data.apps.fao.org/>
- Remote sensing data
- Your own GIS datasets



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Selection of indicators

- **Relevance:** Is the indicator relevant to the environmental system being studied?
- **Data availability:** Is data available geo-spatially for the entire study area?
- **Measurability:** Can the indicator be quantified?
- **Homogeneity:** Is the indicator based on the same source and time period?
- **Reliability:** Is the data source reliable?

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- Some indicators may not be geospatial but may be in tabular format (i.e. by governorate with a data value). In such cases, data can be converted to geospatial format, by joining the table to the governorate GIS shapefile.



Normalisation and classification

Indicators will have varying magnitude and units of measurement



Classify using a unitless common scale (i.e. 1 to 10)

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Normalisation and classification

- GIS Methods
 - Manual interval
 - Equal interval
 - Natural breaks (Jenks classification method)
 - Quantile method
- Expert opinion
- Reference scale
- Min-max normalisation

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- Peer review is recommended to approve selected method.

Classification in GIS

ArcToolbox

- Multidimension Tools
- Network Analyst Tools
- Parcel Fabric Tools
- Schematics Tools
- Server Tools
- Space Time Pattern Mining Tools
- Spatial Analyst Tools
 - Conditional
 - Density
 - Distance
 - Extraction
 - Generalization
 - Groundwater
 - Hydrology
 - Interpolation
 - Local
 - Map Algebra
 - Math
 - Multivariate
 - Neighborhood
 - Overlay
 - Raster Creation
 - Reclass
 - Lookup
 - Reclass by ASCII File
 - Reclass by Table
 - Reclassify
 - Rescale by Function
 - Slice
 - Segmentation and Classification
 - Solar Radiation
 - Surface

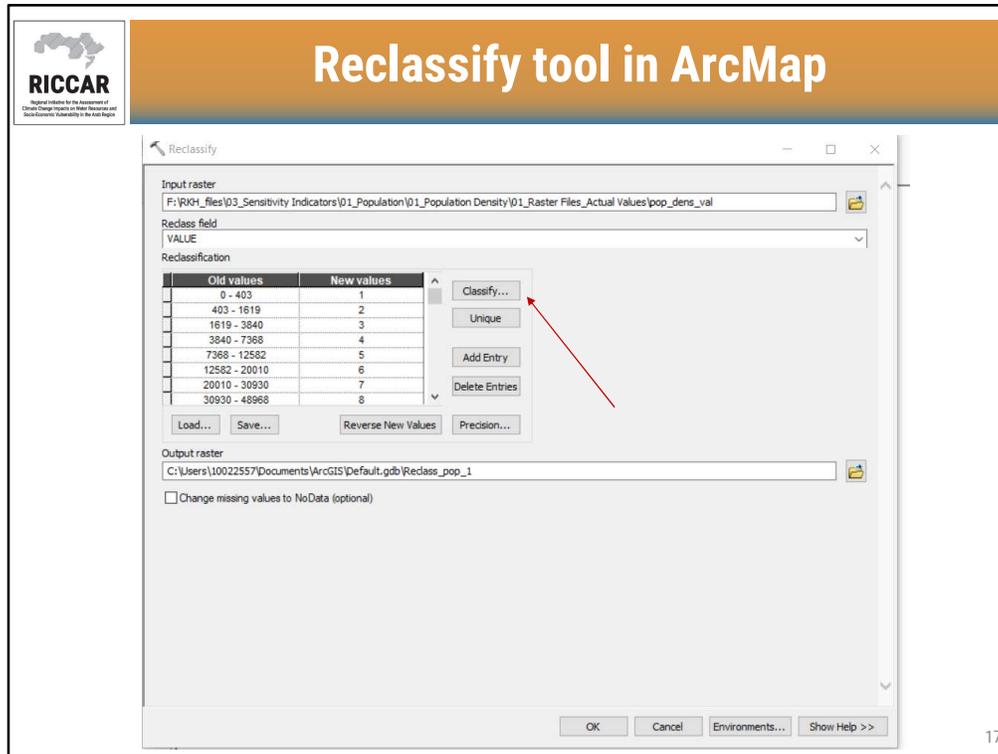
ArcToolbox

- Tracking Analyst Tools
- 3D Analyst أدوات
- ArcGIS Network Analyst أدوات
- Spatial Analyst أدوات
 - إعادة تصنيف حسب الوظيفة
 - إعادة تصنيف
 - إعادة تصنيف بواسطة الجدول
 - إعادة تصنيف بواسطة ملف ASCII
 - بحث
 - شريحة
 - إنشاء بيانات نقطية
 - استخراج
 - استنتاج
 - الإشعاع الشمسي
 - التقسيم والتصنيف
 - الجوار
 - السطح
 - المسافة
 - المياه الجوفية
 - تراكب
 - تصميم
 - خريطة مفاهيم الجبر
 - رياضيات
 - سطح
 - شريطي
 - كثافة
 - مائلات
 - متعدد التغير
 - محلي
 - مضافة
 - نطاقي

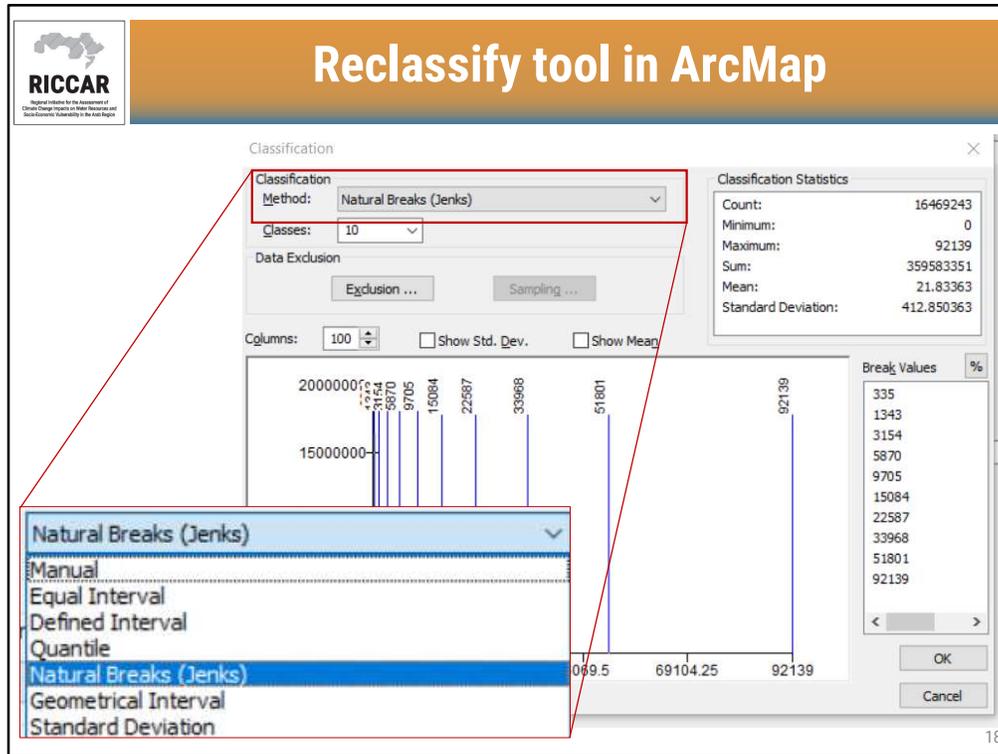
ArcToolbox

- Outils de géocodage
- Outils de gestion des données
- Outils de mise à jour
- Outils de référencement linéaire
- Outils de serveur
- Outils de statistiques spatiales
- Outils d'exploration des modèles spatio-temporels
- Outils multidimensionnels
- Outils Network Analyst
- Outils schématiques
- Outils Spatial Analyst
 - Algèbre spatial
 - Conditions
 - Création de rasters
 - Densité
 - Distance
 - Extraction
 - Généralisation
 - Hydrologie
 - Interpolation
 - Locale
 - Mathématiques
 - Multivariés
 - Nappes phréatiques
 - Rayonnement solaire
 - Reclassement
 - Correspondance
 - Fonction Redimensionner par
 - Reclasser par fichier ASCII
 - Reclasser par table
 - Reclassification
 - Tranche

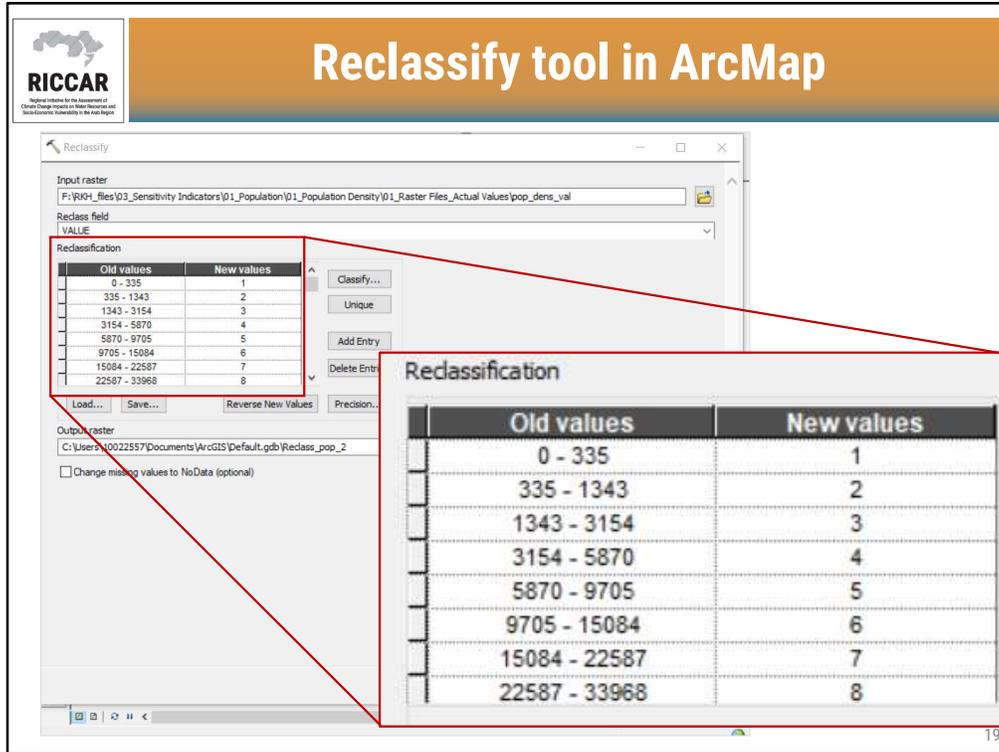
- Use the Reclassify tool found under Spatial Analyst Tools > Reclass.
- Note that users must have the Spatial Analyst license available and activated. Activate by selecting Customize > Extensions.



- For example, reclassify the population density indicator used for RICCAR.
- Select Classify to reclassify the actual values to classified values (i.e. 1 to 10) using GIS.
- Because the raster does not have any gaps, leave “Change missing values to NoData” unchecked.



- User-defined classification method and number of classes.
- The resultant break values will be displayed (i.e. Class 1: 0-335; Class 2: 335-1343, etc)
- It is recommended to conduct peer review of classification methods to best represent the study area:
 - **Manual:** User-defined intervals
 - **Equal interval:** Subdivide attributes into equally-sized ranges
 - **Defined interval:** Specify an interval size used to define a series of classes with the same range of values.
 - **Quantile:** Each class contains an equal number of entities, best used for linearly distributed data.
 - **Natural breaks (Jenks):** Classes are determined by the natural groupings inherent in the data.
 - **Geometric interval:** Class breaks are based on intervals having a geometric series.
 - **Standard deviation:** Calculates breaks based on the difference between a feature's attribute value and the mean.



- Results of reclassification will be shown with the range of actual values on the left and the new classified values on the right.



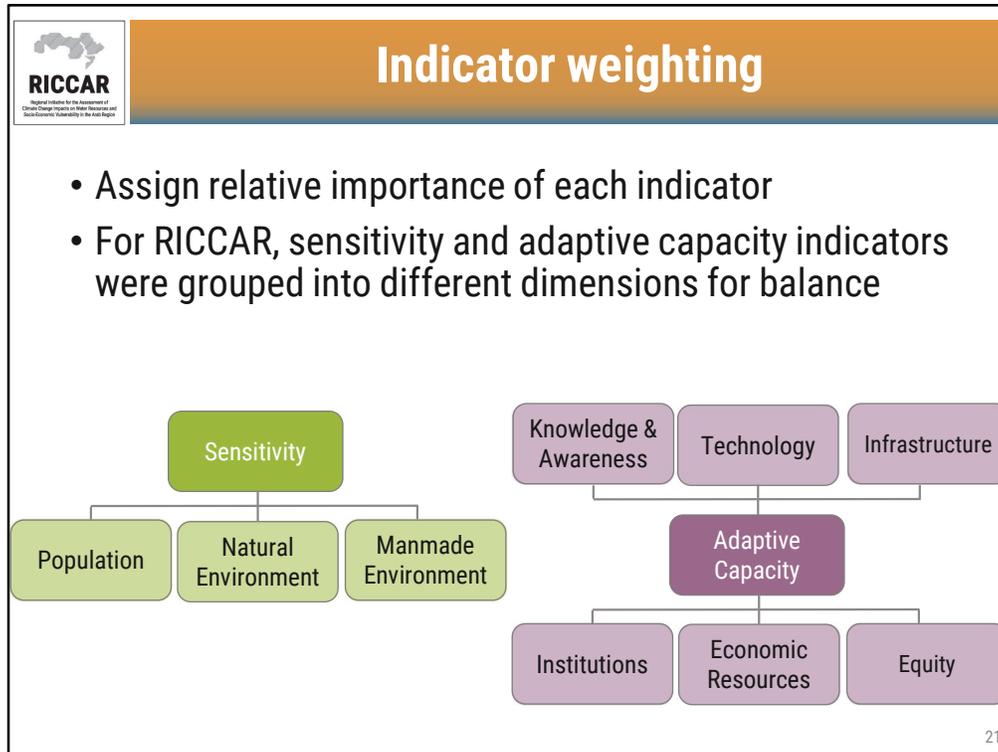
Other reclassification methods

- Expert opinion
 - Suitable for descriptive data (i.e. land use)
- Reference scale
 - Using known scale (i.e. Falkenmark Water Stress Indicator)
- Min-max normalisation
 - Best for metric data sets
 - $X_j = \frac{X_i - X_{min}}{X_{max} - X_{min}}$

X_j	Normalised value
X_i	Actual value
X_{max}	Maximum value of entire range
X_{min}	Minimum value of entire range

Note: Some datasets may be skewed and thus will need log-transformation before normalisation

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- Assign relative importance of each indicator
 - For RICCAR, sensitivity and adaptive capacity indicators were grouped into different dimensions for balance
- Sensitivity indicators were grouped into 3 dimensions: population, natural, and manmade.
 - Adaptive capacity indicators were grouped into 6 dimensions: knowledge and awareness, technology, infrastructure, institutions, economic resources, and equity.



Indicator weighting

Selected weighted scheme will have significant effect on vulnerability assessment

- Statistical methods
 - Principal component analysis and exploratory factor analysis (PCA/EFA)
 - Data envelopment analysis (DEA)
 - Linear regression
 - Multi-criteria decision analysis
- Participatory approaches
 - Budget allocation process (BAP)
 - Analytic hierarchy process

Equal weighting is not the absence of weighting and should be justified by participatory approaches

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- A sensitivity analysis is recommended to further justify selected weighting scheme.
- RICCAR used budget allocation process by sending surveys to experts across the Arab region in different water-related sectors.



Aggregate indicators

Arithmetic aggregation

$$\text{Composite index value} = (w_1 \times X_1 + w_2 \times X_2 + w_3 \times X_3 + \dots + w_n \times X_n)$$

Geometric aggregation

$$\text{Composite index value} = X_1^{w_1} \times X_2^{w_2} \times X_3^{w_3} \times \dots \times X_n^{w_n}$$

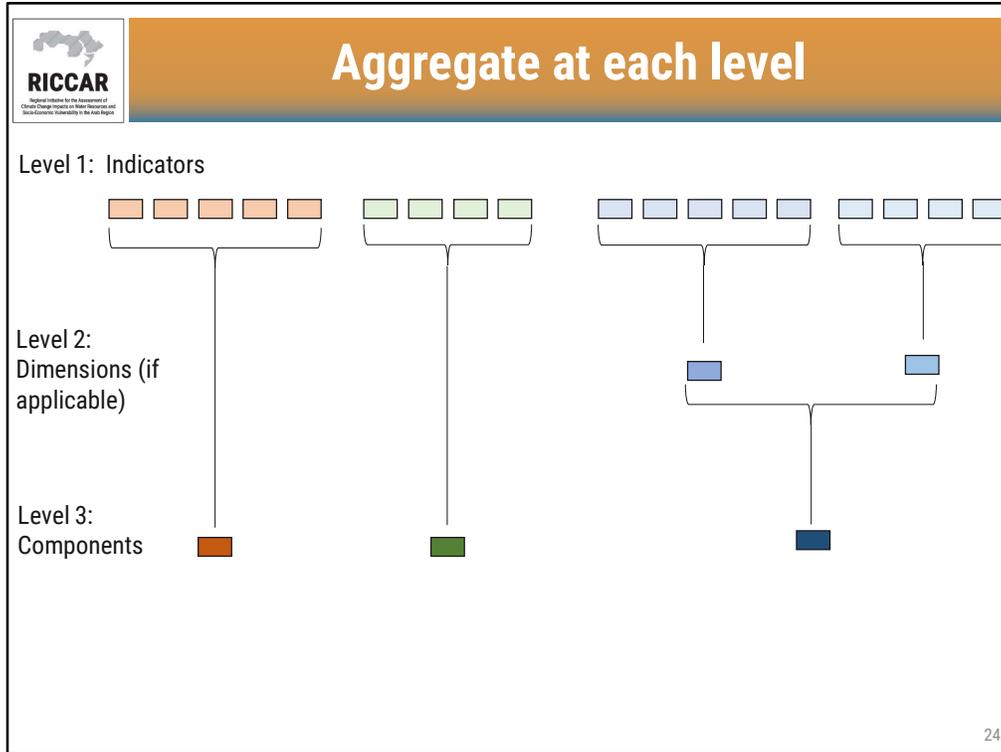


X_n Normalised value of indicator i

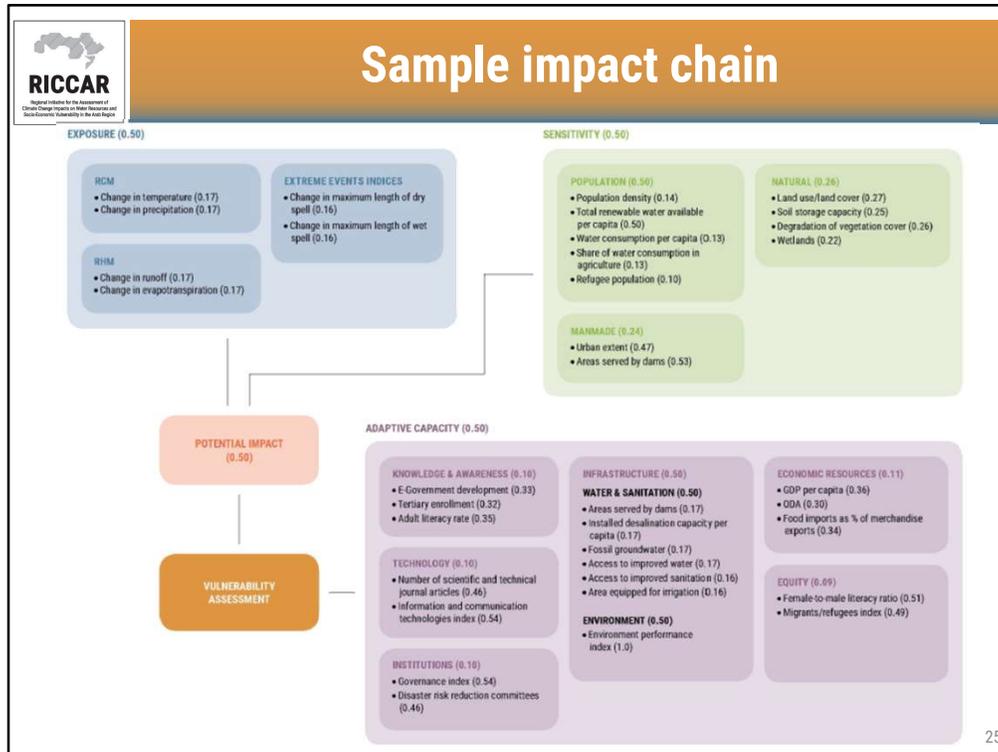
w_n Weight for indicator i

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- Indicators should be aggregated together to create a composite index value.
- Arithmetic aggregation tends to offer full compensability, whereby poor performance of some indicators can be compensated by sufficiently high values of other indicators. For example, if a hypothetical composite indicators was formed by inequality, environmental degradation, GDP per capita and unemployment, two countries, one with values (21,1,1,1) and the other with (6,6,6,6) would have equal composite indicator value (=6) under an additive aggregation. Obviously the two countries would represent very different social conditions that would not be reflected in the composite.
- Geometric aggregation is preferred because it offers partial compensability. In the example described above, the first country would have a much lower composite indicator value (=2.14) than the second country (=6.00) under the geometric aggregation. The use of geometric aggregation can also be justified on the grounds of the different incentives they apply to countries in a benchmarking exercise.



- Aggregate at each level: indicators, then dimensions (if applicable), then components (exposure, sensitivity, adaptive capacity)



- Impact chains show the cause and effect relationship between indicators, dimensions, components, and vulnerability.
- Indicator selection is an iterative process. It is advised to develop an impact chain at the beginning of the vulnerability assessment study to brainstorm which indicators may be most relevant to the study (whether it be impact on crops, impact on coastal areas, etc.). Indicator selection may be revised based on data availability.
- The number in parentheses is the weight of each element, at that aggregation level. Element weights for each level should sum to 1.0.
- This is the impact chain for Change in Water Availability studied for RICCAR.
- Note for RICCAR, the Infrastructure dimension was further divided into pillars. Five pillars were used to classify indicators: (a) energy, (b) transportation, (c) health, (d) water and sanitation, and (e) environment. Only 2 pillars were used for this particular subsector/impact chain (water and sanitation and environment).

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Perform geometric aggregation in ArcMap

ArcToolbox

- Geocoding Tools
- Geostatistical Analyst Tools
- Linear Referencing Tools
- Multidimension Tools
- Network Analyst Tools
- Parcel Fabric Tools
- Schematics Tools
- Server Tools
- Space Time Pattern Mining Tools
- Spatial Analyst Tools
 - Conditional
 - Density
 - Distance
 - Extraction
 - Generalization
 - Groundwater
 - Hydrology
 - Interpolation
 - Local
 - Map Algebra
 - Raster Calculator
 - Math
 - Multivariate
 - Neighborhood
 - Overlay
 - Raster Creation
 - Reclass
 - Segmentation and Classification
 - Solar Radiation
 - Surface
 - Zonal
- Spatial Statistics Tools

ArcToolbox

- Tracking Analyst Tools
- 3D Analyst أدوات
- ArcGIS Network Analyst أدوات
- Spatial Analyst أدوات
 - إعادة تصنيف
 - إنشاء بيانات نقطية
 - استخراج
 - استنتاج
 - الإشعاع الشمسي
 - التقسيم والتصنيف
 - الجوار
 - السطح
 - المسافة
 - المياه الجوفية
 - تراكب
 - تعميم
 - خريطة مقاييس الجوار
 - حاسبة البيانات النقطية
 - رياضيات
 - سطح
 - مترطبي
 - كثافة
 - مائلات
 - متعدد المتغير
 - محلي
 - مسافة
 - نطاقى
 - أدوات إدارة البيانات
 - أدوات إسناد خطى
 - أدوات الإحصاء المكاني
 - أدوات التحرير
 - أدوات التحليل

ArcToolbox

- Outils de géocodage
- Outils de gestion des données
- Outils de mise à jour
- Outils de référencement linéaire
- Outils de serveur
- Outils de statistiques spatiales
- Outils d'exploration des modèles spatio-temporels
- Outils multidimensionnels
- Outils Network Analyst
- Outils schématiques
- Outils Spatial Analyst
 - Calculatrice raster
 - Conditions
 - Création de rasters
 - Densité
 - Distance
 - Extraction
 - Généralisation
 - Hydrologie
 - Interpolation
 - Locale
 - Mathématiques
 - Multivariés
 - Nappes phréatiques
 - Rayonnement solaire
 - Reclassement
 - Segmentation et classification
 - Superposition
 - Surface
 - Voisinage
 - Zonaux

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- Use Raster calculator found under the Spatial Analyst Tools > Map Algebra.
- Note that users must have the Spatial Analyst license available and activated. Activate by selecting Customize > Extensions.

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Perform geometric aggregation in ArcMap

Raster Calculator

Map Algebra expression

Layers and variables

- refugees_va
- h2o_ag_va
- h2o_cons_va
- tarivr
- pop_dens_va

7 8 9 / == != &
4 5 6 * > >= |
1 2 3 - < <= ^
0 . + () ~

sqrt
Ln
Log10
Log2
Mod
Power
RoundDown
RoundUp

Use power function

Power("pop_dens_va",0.14) * Power("tarivr",0.5) * Power("h2o_cons_va",0.13) * Power("h2o_ag_va",0.13) * Power("refugees_va",0.1)

Output raster
c:\users\10022557\documents\arcgis\default.gdb\pop_dens_va_1

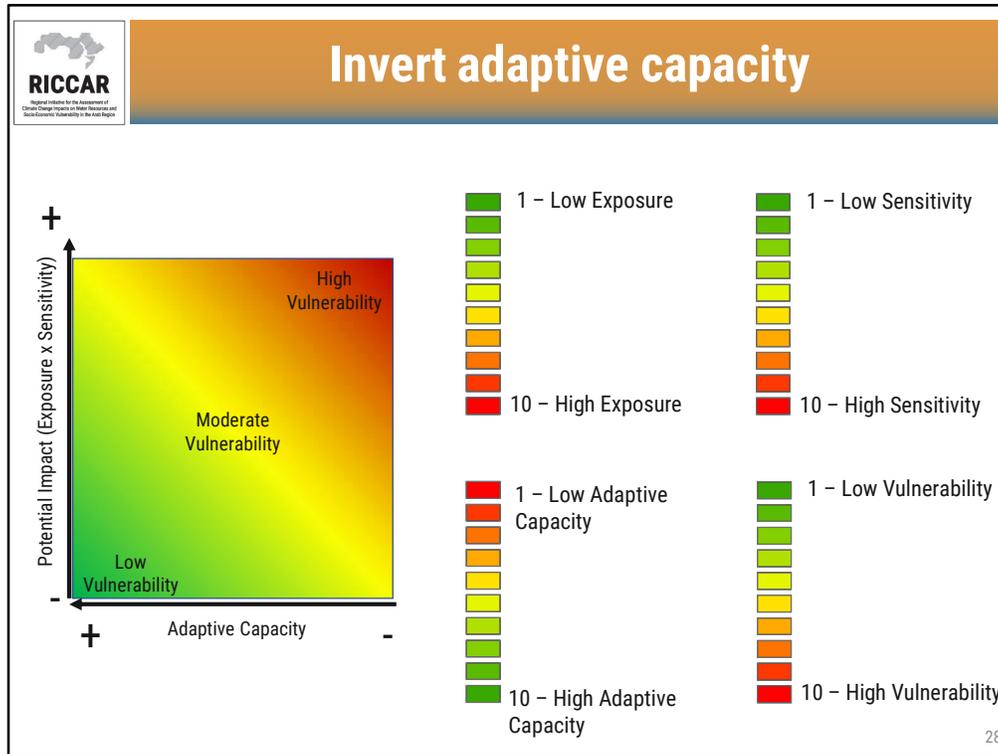
Equation written in raster calculator as:

Power(indicator1,weight1)*Power(indicator2,weight2)*Power(indicator3,weight3)*...*Power(indicatorn,weightn)

OK Cancel Environments... Show Help >>

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- Example is aggregating the sensitivity indicators for the population dimension, shown on the impact chain on slide 25.
- Repeat for each level of aggregation.



- Exposure, sensitivity, and potential impact will have values of 1 representing a favorable condition (i.e. low exposure), and 10 representing an unfavorable condition (i.e. high exposure). The “stoplight” color scheme helps represent these values in GIS mapping.
- Adaptive capacity, on the other hand will have values of 1 representing an unfavorable condition (i.e. low adaptive capacity) and 10 representing a favorable condition (i.e. high adaptive capacity).
- Thus to maintain all favorable values together and all unfavorable values together, the adaptive capacity indicators must be inverted prior to aggregating to determine vulnerability.

Perform geometric aggregation (invert Adaptive Capacity)

Raster Calculator

Map Algebra expression

Layers and variables

- literacy_va
- enroll_va
- e-gov_va

Power((11-'e-gov_va'),0.33) * Power((11-'enroll_va'),0.32) * Power((11-'literacy_va'),0.35)

Output raster

c:\users\10022557\documents\arcgis\default.gdb\egov_va_rast

Equation written in raster calculator as:

Power((11-indicator1),weight1)*Power((11-indicator2),weight2)*...*Power((11-indicatorn),weightn)

OK Cancel Environments... << Hide Help

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- To invert the adaptive capacity indicator values, subtract from 11 (for indicator values which range from 1 to 10). The resultant range will still be 1 to 10, but values of 1 now represent a favorable condition (i.e. high adaptive capacity) and values of 10 will now represent an unfavorable condition (i.e. low adaptive capacity).



Key points on indicators and aggregation

- Indicators must geospatially include the entire area of study. (Cannot aggregate gapped areas.)
- Weights should sum to 1 for each level of aggregation. (Indicators > Pillars > Dimensions > Components)
- There is no ideal number of indicators. Because indicators are aggregated based on classified values (not actual values), may be able to present vulnerability with just a few indicators.

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- Note that although Pillars and Dimensions were used for RICCAR, this is not necessary. Indicators can be directly aggregated into each of the 3 components (Exposure, Sensitivity, Adaptive Capacity).

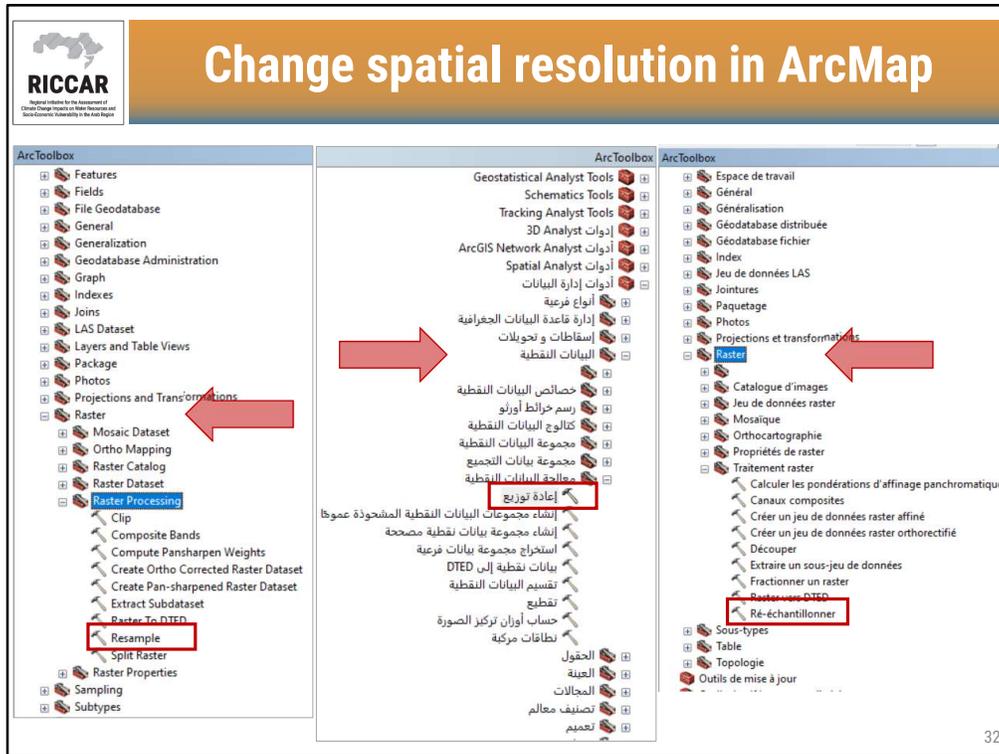


Key points on indicators and aggregation

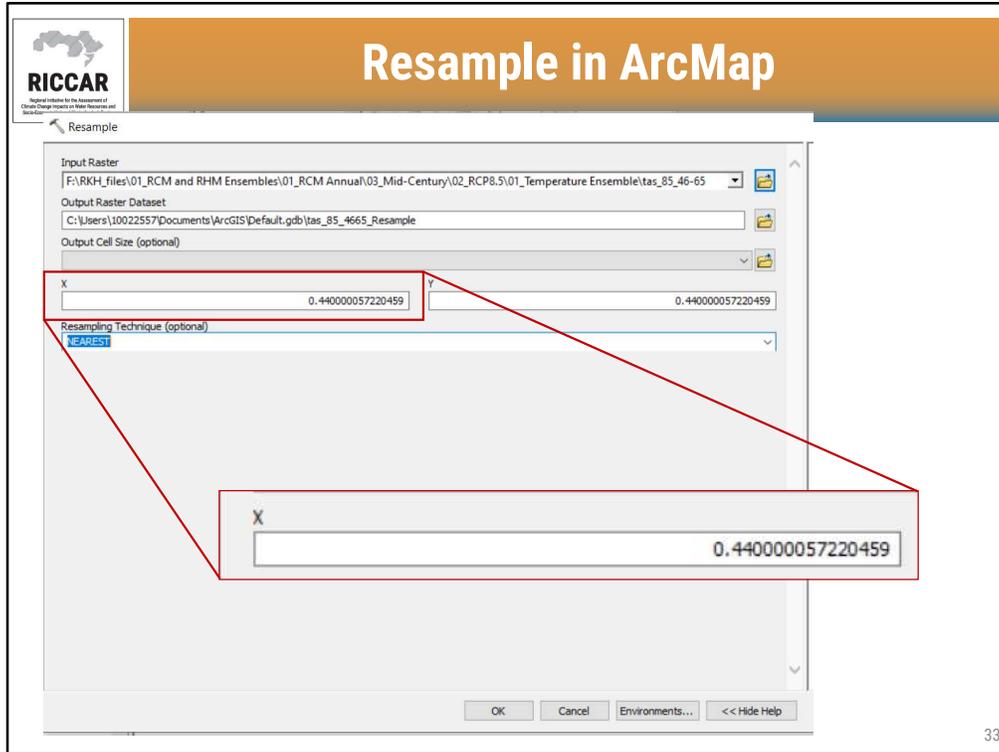
- Each indicator should be independent of one another, having weak or no correlation.
- All indicators should be in raster format to facilitate aggregation.
- Range of values after each aggregation values should be 1 to 10 (if each indicator had a range from 1 to 10). If range of values exceeds this, there is an error in aggregation.
- Indicators should have same spatial resolution.

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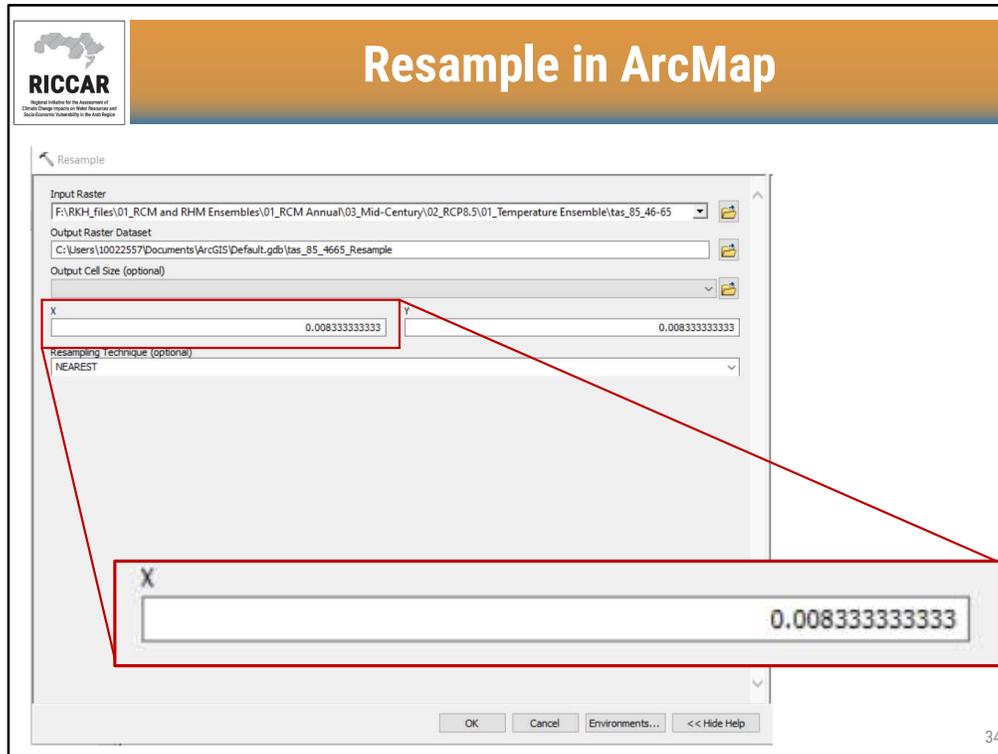
- Some indicators may be in shapefile format. In such cases, convert to raster using the Polygon to Raster tool, found under Conversion Tools > To Raster.



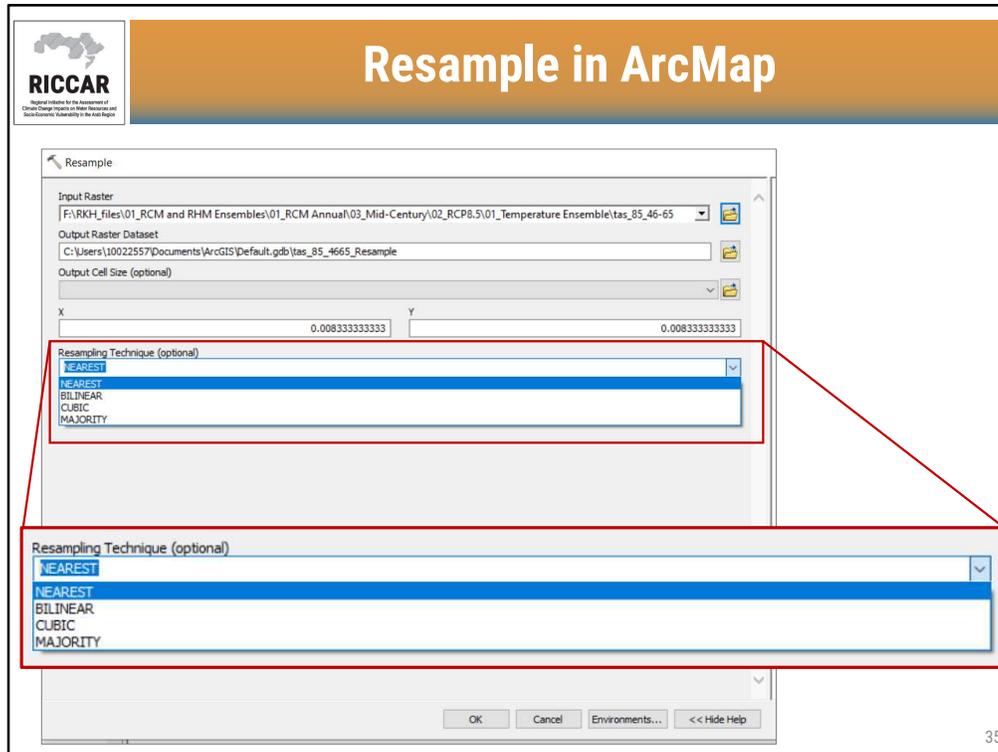
- Resample tool found under Data Management Tools > Raster > Raster Processing



- For example, resample temperature data for mid-century, RCP8.5
- Output cell size is user-defined and almost always be defined by degrees, rather than kilometres. May need to use measurement tool in GIS to confirm.



- Indicators used for RICCAR were all resampled to ~ 1 km grid cell size (=0.008333333 degrees).
- Be sure to enter the same size for both X and Y to maintain square grid cell.



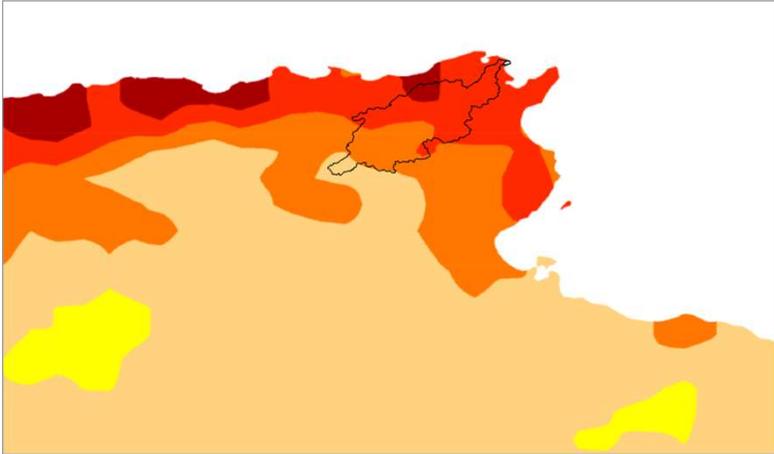
- Different resampling techniques to select from:
 - **Nearest:** Minimizes changes to pixel values since no new values are created. Best used for discrete data, such as land use.
 - **Bilinear:** Interpolates value of each pixel by averaging the values of the 4 surrounding grid pixels.
 - **Cubic:** Interpolates value of each pixel by averaging the values of the 16 surrounding grid pixels.
 - **Majority:** Determines the value of each pixel based on the most popular value in a 3 x 3 window. Best suited for discrete data.
- To resample vulnerability assessment indicators, either Bilinear or Cubic is recommended. For RICCAR, Cubic resampling was used.



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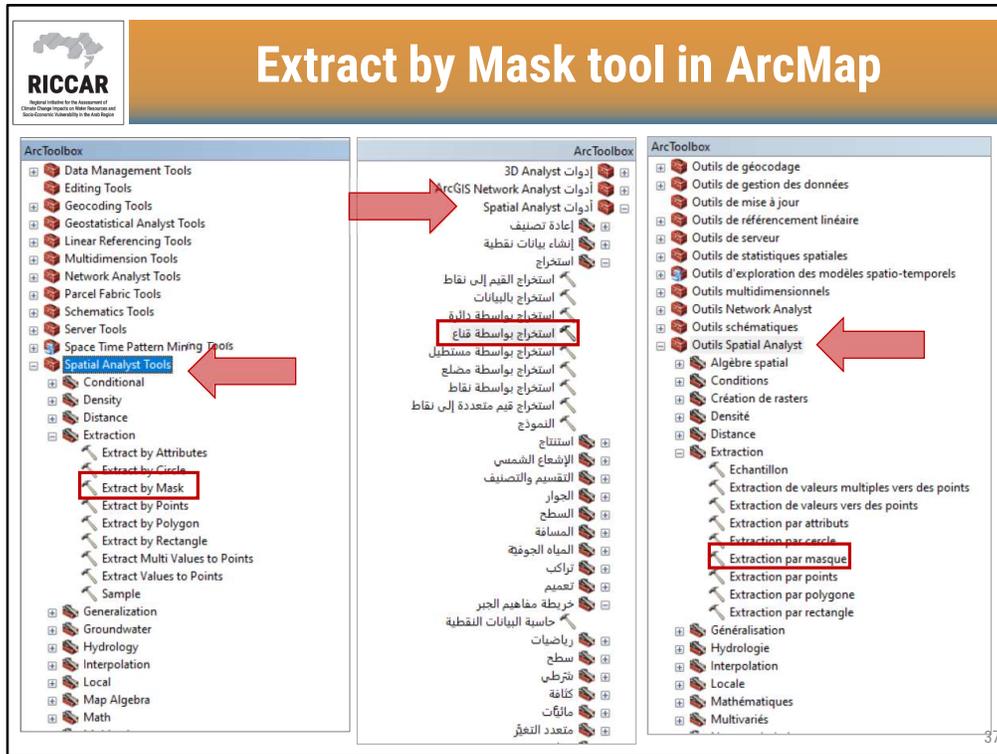
Clipping to area of interest

GIS datasets may cover a larger spatial area than the vulnerability assessment study area

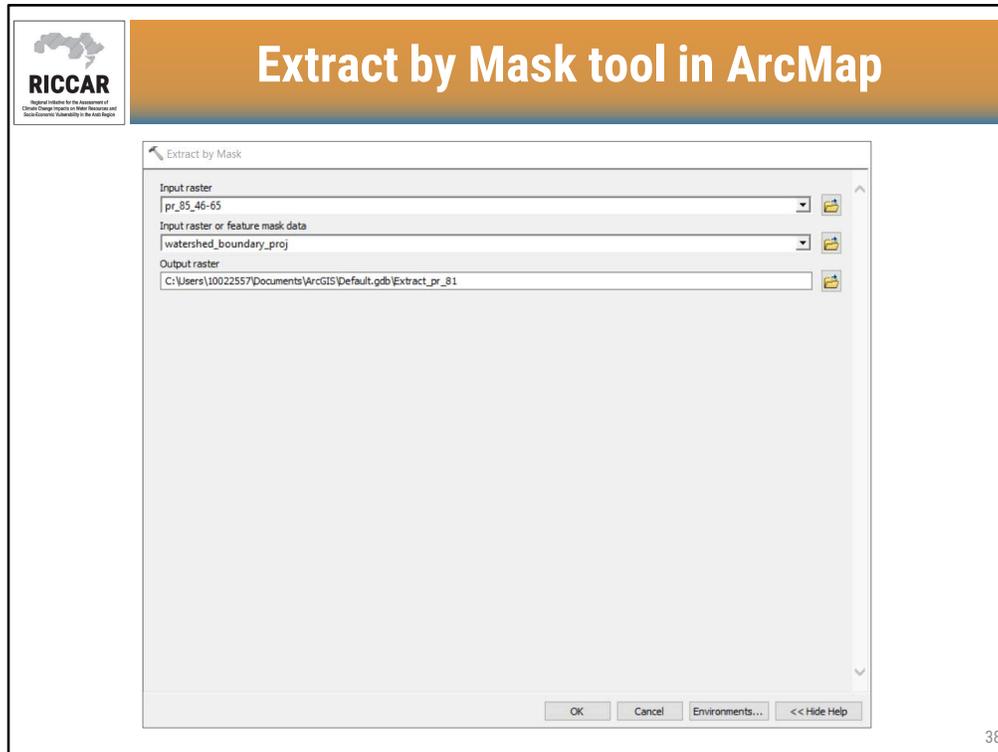


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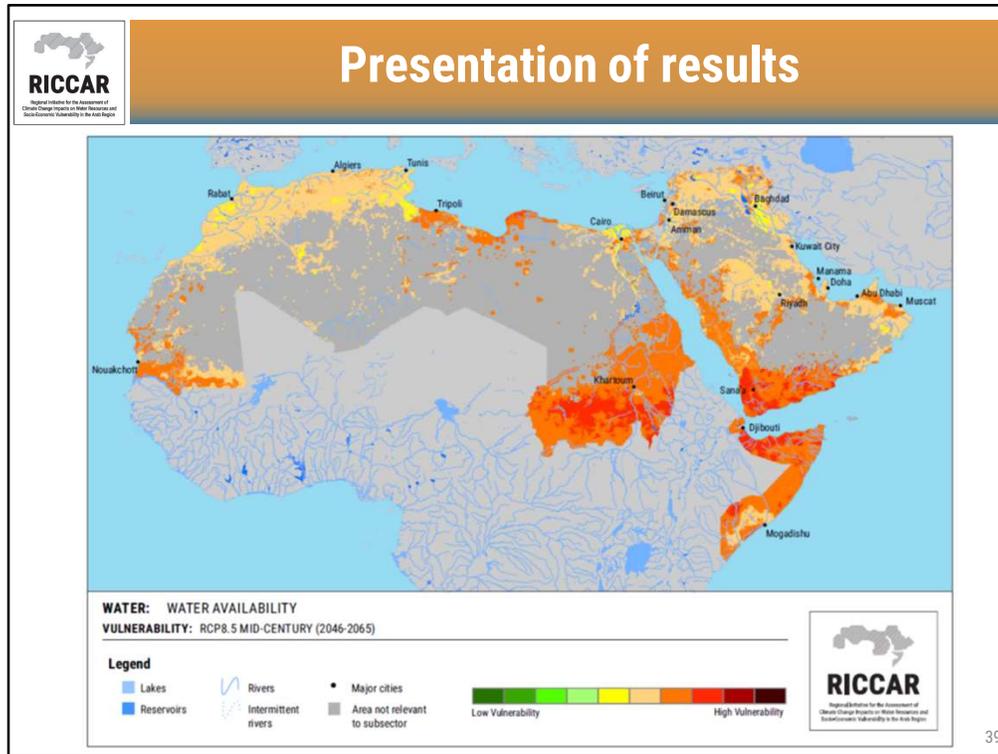
- For example, clipping precipitation indicator to Medjerda River basin.



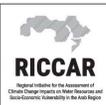
- Cannot clip a raster the same way as clipping a shapefile (using Clip tool).
- Extract by mask to clip a raster to area of interest, found under Spatial Analyst Tools > Extraction.
- Note that users must have the Spatial Analyst license available and activated. Activate by selecting Customize > Extensions.



- Enter input raster, the “mask” (either a shapefile or other raster used to clip), and the user-defined output raster.



- Example vulnerability map from RICCAR.
- Low vulnerability: green; moderate vulnerability: yellow; high vulnerability: red.
- For RICCAR, decided to only show results for area of interest for each subsector (not the entire Arab region). For this subsector, the study area for water availability was based on populated areas, rangelands, crops, wetlands, and forests.



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Climate Change Impacts on Water Resources and
Socio-Economic Vulnerability in the Arab Region

Exercise

1. Given: Temperature and precipitation ensembles for mid-century RCP8.5
2. Reclassify values using manual classification

Class	Range of values	
	Change in Temperature (°C)	Change in Precipitation (mm/month)
1	< 1.0	> 8
2	1.0 – 1.5	6 – 8
3	1.5 – 2.0	4 – 6
4	2.0 – 2.5	2 – 4
5	2.5 – 3.0	0 – 2
6	3.0 – 3.5	-2 – 0
7	3.5 – 4.0	-4 – -2
8	4.0 – 4.5	-6 – -4
9	4.5 – 5.0	-8 – -6
10	> 5.0	< -8

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- Note that not all classes may be used.



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Exercise

3. Resample temperature and precipitation indicators to ~ 1 km.
4. Aggregate indicators using a weight of 0.4 for temperature and 0.6 for precipitation.
5. Extract results based on Medjerda River basin shapefile (given).
6. Reclassify output using equal interval and map using “stoplight” color scheme.

Final result:



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The slide features a background image of a desert landscape at sunset. In the foreground, there is a stylized map of the region. The text 'Thank You' is centered at the top. Logos for RICCAR and the UN ESCWA are present. Contact information for Marlene Ann Tomasziewicz is provided in the bottom left.

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ريكار
المعهد الإقليمي لتقييم الأثر المناخي على
الموارد المائية في المنطقة العربية
والضعف الاجتماعي والاقتصادي

Thank You

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